Cone penetration testing, CPTu

Preface

Environmental Mechanics AB or short Envi is a Swedish company developing, producing and marketing systems for cone penetration testing (also known as CPT or CPTu) in our facilities in Sweden. We also manufacture equipment for drill data recoding (an acronym is MWD).

This document is intended to be an introduction to cone penetration testing for someone who knows little or nothing about the subject. A CPTu probe is used to penetrate the ground to a level where it is no longer possible to go any deeper or when the test depth is considered sufficient. This procedure is often referred to as a push and is executed at a constant speed of 2 cm/sec during which data from several sensors in the probe are registered. You can be piggyback several additional/optional sensors to the CPT probe. As of today we can provide both seismic module and a resistivity module for add on to our CPT probe. Our CPTu probe is called Memocone. It has a built in computer with a memory where data is stored.

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History

Ground investigations using cone penetration was first done in the Netherlands in the early 1930th. They used a mechanical penetrometer. Electrical cones were first developed around early 1960th but came into more common use in the 1980th when the piezometer had been developed. The first cones could only read tip force and later sleeve friction. The new piezometer probe could read also pore water pressure giving you the possibility to determine ground water level. This probe type is also known as a CPTu.

Envi was started around 1985 and delivered the first drill data logger a year later and the first CPTu probe not much later. The cone is known as Memocone. The name indicates it's built in electronic memory making wireless operation possible. Since then Envi has developed a seismic add-on enabling SCPTu investigations and a resistivity add-on enabling resistivity/conductivity measurement to be executed at the same push as CPT investigation is done. This document will focus on the basic CPTu functionality and leave the add-ons for later descriptions.

Since the company was started Envi has developed and sold several generations of CPTu probes and data loggers. The current model is called Envi Logger C2 Bluetooth. This logger was introduced to market in 2018. It is PC based and fully digital. Communication between PC and logger is over Bluetooth so no cable required. Below is an image of the logger and typical rugged outdoor tablet PC.



The Memocone without battery tube, cable tube or acoustic transmitter tube



Complete probe set including Memocone, battery tube, the yellow wheel on the rod depth transducer + accessories.



The image below shows a basic system including pushing machine, in this case a truck, and the parameters that are measured.



What is measured?

When running CPT tests you push down a probe into the ground. This is a type of in-situ testing. Data from the CPT probe can be sent to surface during penetration by means of a cable or by using a cordless acoustic system. You can also run the Memocone CPTu in memory mode without real time data and closely monitor your rig feed force output. The drawback of using memory mode is that you cannot know if you begin to come close to maximum load or if the probe starts going at an angle. Regardless of what type of equipment you use what really matters are:

- 1. Your measurement is correct and complete
- 2. You know how to translate your sensor data to real world aspects (i.e. how to translate probe data into soil types)

To satisfy §1 you should calibrate the cone on a regular basis according to requirements in the standard that you follow. Preparation of the cone should be done according to manufacturer advice.

To satisfy §2 you either use a commercial software for data interpretation or do the calculations yourself. The most widely used interpretation model is perhaps Robertson and Campanella 1983 and more recent updates based on the same model made by Dr. Robertson. There are also other interpretation models such as Eslami Fellenius but that model seems less popular.



Parameters normally measured are:

Time

Penetrated depth. When you combine Time and Depth you can get rate of penetration or short ROP which describes how fast you are pushing. Normal push speed for CPT is 2 cm/second. The allowed offset from 2 cm/second is defined in the standard you follow. Depth resolution varies between different systems but Envi Logger C1 has default depth resolution of 1 cm. You can adjust that to any integer number of cm > 0

Tip force also known as Qc. This is measured in MPa which is a bit odd for force but this is quite clever since it makes tip area unimportant and thus enabling use of different size probes with the same result for the same soil type.

Sleeve friction, also known as Fs. This is measured in kPa for the same reason as Qc is measured in Mpa

Pore pressure. There are three different pore pressures that can be measured according to current standards, called U_1 , U_2 and U_3 . A majority of CPT probes are equipped with only the second pore pressure sensor, also known as U_2

Inclination. This parameter is for registering how much the probe is inclining (at an angle as compared to vertical)

Temperature. This can be important since it may have an impact on electronics and sensors. The Envi Memocone is equipped with built in compensation for temperature changes so you need not consider this. Only if temperature changes very swiftly it has an impact on the Memocone CPTu since there is some small delay in compensation. Normally very quick temperature changes, like decades of degrees in seconds, do not occur. General rule is to try to keep the CPTu probe at the temperature you have in the ground to be investigated.

Commonly used add-ons to the CPT are:

Resistivity add-on for registering ground resistivity/conductivity. This can be used for determining moisture and salt content in ground

Seismic add-on can be used as a complement for cross referencing and validating soil type determination from CPT parameters

How are parameters measured?

Most parameters when running CPT tests are registered in the probe itself but depth is measured separately. I will not describe time since that is not an actual parameter but more like an index.

Depth is measured using a multiturn encoder with 12 bits single turn resolution and 18 bits multiturn resolution and CANopen interface. The transducer is normally IP67 but also IP69k is available. The sensor is typically mounted on a rope length house with wire as per image to the left below or using a mounting bracket on the drill unit and supplying the axle with a cogwheel + a chain will be mounted all along the mast as per image in the middle below. Another common depth meter is the wheel on the rod solution as depicted to the right below. This can be mounted and demounted easily and can "travel with the system" if you want to use one registration system on several drill rigs or equivalent.



Feed force is not a mandatory parameter but if you want to register it you can measure it in several ways:

1. You use a strain gauge to get data. This is typically done using an S-shaped load cell

2. You read hydraulic pressures on both sides of the hydraulic piston and account for piston area on both pulldown and holdback side of the piston to calculate feed force.

Either solution above requires that you calibrate the sensor output to an actual force. This calibration must be able to compensate for possible non linearity. This is done by using a very accurate scale that has been calibrated by some accredited institute. Machine force is only logged for informative use. It is not used for determining soil type.

Qc, Fs, U2 + some more (as per earlier chapter) are all measured by/in the probe.

The probe is pushed into the ground at a speed of 2 cm/second until you reach a predefined depth or the probe cannot be pushed any further due to obstacles or when you fulfill whatever the criteria are for terminating the push. The machine to push the CPT into the ground can be a simple manually moved push frame or a more sophisticated crawler or truck. Envi produce a simple pusher and a more advanced mini crawler. Both with the ability to push with 20 tons force

Example of Envi push rigs are:



The Envi 20 ton Compact Crawler Hand maneuvered with excellent load bearing capability also on very soft soils

The Envi pusher. Can be transported on a pickup and manually moved when on site using the combined transportand power pack trolley

The Envi Memocone has built in electronics and stores data for all parameters in memory. After retraction of the Memocone data is downloaded to the PC and shown on screen. Data can be exported in a tab separated format suitable for import with Excel or equivalent or in Nordic standard format which is a tagged format. Data in files can be imported into your preferred type of analysis software for further analysis. The C2 system can determine soil type etc in software also during the push if you have real time display of data (cable or cordless acoustic). So you can see soil determined from Robertson and Campanella 1983 directly on screen in real time in the application window.

Why do CPT tests?

CPT tests can be done for several reasons. The most obvious being:

Ground investigations to know the strata before planning for construction of buildings, roads, bridges, railways etc

Determine ground water level and if you have good pore pressure accuracy also hydrological flux

The most obvious benefit of using the CPT rather than soil sampling is of course time and cost. You will be able to investigate a lot more using the CPT than a soil sampler. You can achieve very accurate perception of the grounds strata provided in soil. The CPT should not be used in ground where there are pebbles or boulders and of course also not in rock. For these harder layers drill data recording or core sampling is required.

If you combine CPTu investigations with some soil samples you will have a very good perception of the ground conditions in the area you have investigated.

Some case stories

On our homepage www.envi.se you can see some case stories. We have tried to gather information about some different types of users and how they benefit from having our systems.

References

A detailed description of CPT usage and also seismic test http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_syn_368.pdf

One of the most important books on the subject is: http://books.google.com.hk/books?id=ofbnE1xMl_kC&printsec=frontcover&hl=sv&source=gbs_g e_summary_r&cad=0#v=onepage&q&f=false